National Aeronautics
and Space Administration

Draft LunaNet Interoperability Specification

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1. INTRODUCTION

Under the guidance of NASA's Space Communication and Navigation (SCaN) program, this document, along with its companion documents, LunaNet Services Requirements Document (TBD) and the LunaNet Concept of Operations and Architecture (TBD), provides the basis for a comprehensive set of requirements for operation of a lunar communications and navigation network capable of interoperating with other networks compliant with the Lunar Network (LunaNet) for services to the human exploration, lunar science, and space technology missions. LunaNet will start with a simple architecture of a few nodes to meet the needs of the early missions and evolve to meet the growing needs of a sustained lunar presence. All relay network services are not expected to be met by a single spacecraft platform, or node. The expectation is that the needs of NASA, its partners and other users will be met through a combination of interoperable systems provided by NASA, international partners, and commercial providers. Interoperability across this network-of-networks can be achieved through negotiation of mutually-agreed-upon standards that will be reflected in this document and in the specifications defined by other participants in the combined, cooperative lunar network.

1.1 Purpose

The purpose of this interoperability specification is to define the standard services and interfaces for LunaNet service providers to provide interoperable services to meet the needs of missions operating in the lunar vicinity.

This current document captures all services and needs for LunaNet, as currently identified. These needs are expected to be met through a consortium of providers, including several NASA programs and programs managed outside of NASA. To the extent that providers of these services follow mutually-agreed-upon standards for the services and interfaces, which would be reflected in this document, the combined network can provide seamless services to multiple users. Providers may also provide services and interfaces beyond those specified here with no assurance of interoperability.

Appendix A contains a table allocating these specifications to two operational time periods. These time periods are an Initial Operations Capability (IOC) phase and Enhanced Operations Capability (EOC) phase. The specifications that are currently necessary to support the NASA Artemis III, Artemis IV, and Artemis V missions, as well as Commercial Lunar Payload Services (CLPS) missions, have been allocated to the IOC. Those missions were used as the rationale for inclusion in the IOC to define the minimum needs, but other non-NASA missions are expected in the same time period. As these missions are identified, the IOC specifications may change.

1.2 Scope

This document defines the standards and specifications for interoperations within LunaNet on the lunar surface and in cislunar space. NASA is seeking international and commercial inputs in order to reach consensus on the contents of this document.

This document will provide the necessary guidance for potential providers and users to design and build systems compatible with the broad LunaNet architecture. These standards and specifications are intended for broad use by all parties operating in cislunar space and will be levied as requirements on systems and services required to be interoperable.

2. LUNANET INTEROPERABILITY OVERVIEW

The term “LunaNet” encompasses all systems that provide communications and navigation (or position, navigation, and time (PNT)) services to user systems on and around the Moon (User Lunar Segment) and the users associated systems on Earth (User Earth Segment). As seen in Figure 1, LunaNet has a Lunar Segment and an Earth Segment. The LunaNet Lunar Segment contains elements that could either be in lunar orbit or on the lunar surface. Though they may be referred to in general as “lunar relays,” it is possible that some elements of the LunaNet Lunar Segment may not provide any communications relay functions, but support PNT or other non-data relay functions. The User Lunar Segment may interface with LunaNet by either an interface with the LunaNet Lunar Segment or with the LunaNet Earth Segment. The LunaNet Earth Segment is comprised of Earth ground stations. Note that there are also interfaces between the LunaNet Lunar Segment and the LunaNet Earth Segment. The interface between a LunaNet Lunar Segment element and a LunaNet Earth Segment element may be either intra-network, i.e., within a network provided by a single provider, or it may be inter-network, i.e., between cooperating providers. Standardization of the Lunar Relay-Earth Interface will enable the inter-network or cross support of lunar relays by multiple providers of ground stations. The Lunar Relay-Earth Interface shown in Figure 1 is an intra-network example and the single provider in this case may use a non-standardized interface. The LunaNet Lunar Relay-User Interface and LunaNet-Direct-to-Earth Interface are standardized. The interface between the LunaNet Earth Segment and the User Earth Segment will also be standardized. Note that the User could provide a private direct link between its Lunar and Earth Segments. This is outside the scope of LunaNet and not addressed in this specification.

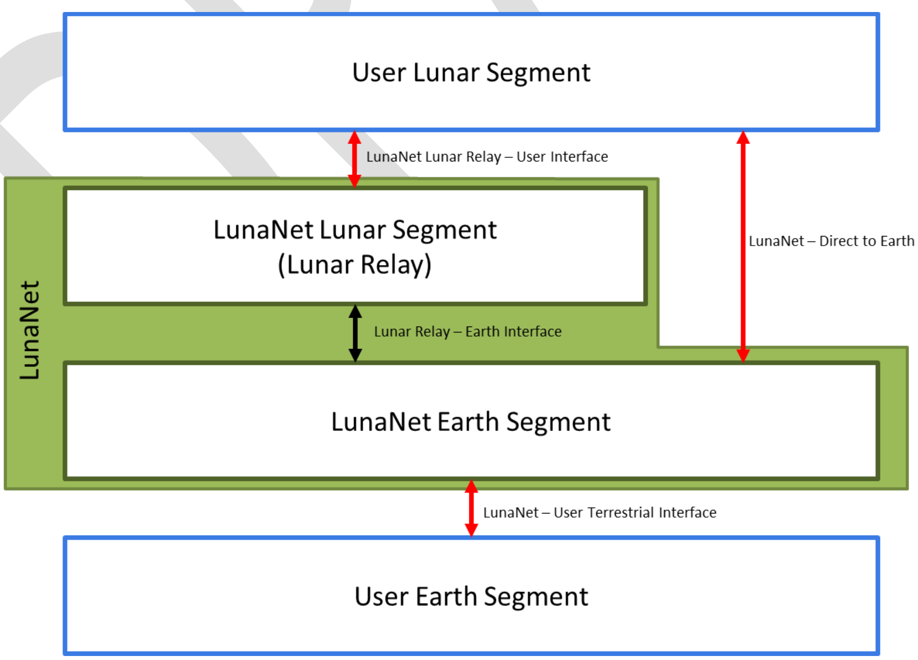

Figure 1 - LunaNet Segments

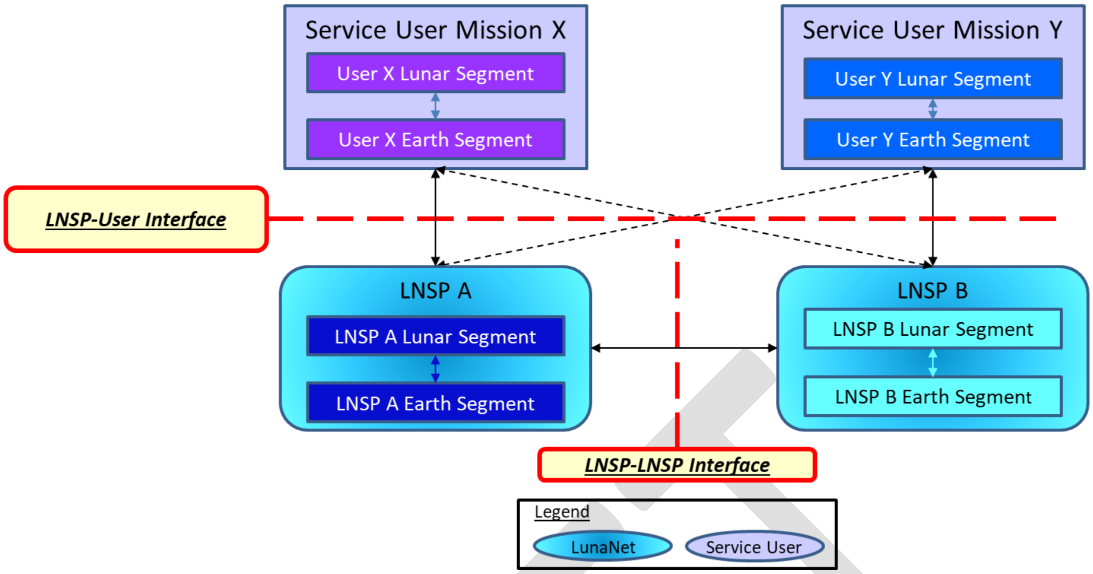

Figure 2 - LunaNet Standard Services and Interfaces between LNSPs and Users

Like the terrestrial internet, LunaNet will be built up through multiple LunaNet Service Providers (LNSPs) combined together to provide services to users. To allow users to receive those services from any provider such that it appears as a single provider to that individual user, two categories of interoperable interfaces are required (See Figure 2).

The first category is the LNSP-User Interface which includes the service interfaces between a user and a provider. These include both the physical interfaces and the protocols and messages that provide services over those interfaces. A user shall be able to operationally receive the same service from different providers in the same way, such that the user will be able to use any connection as a LunaNet access point.

The second category is the LNSP – LNSP Interface. These include both the physical interfaces and protocols and messages that allow different LNSPs to work together to provide the larger LunaNet infrastructure by augmenting individual LNSP capabilities with LNSP partners.

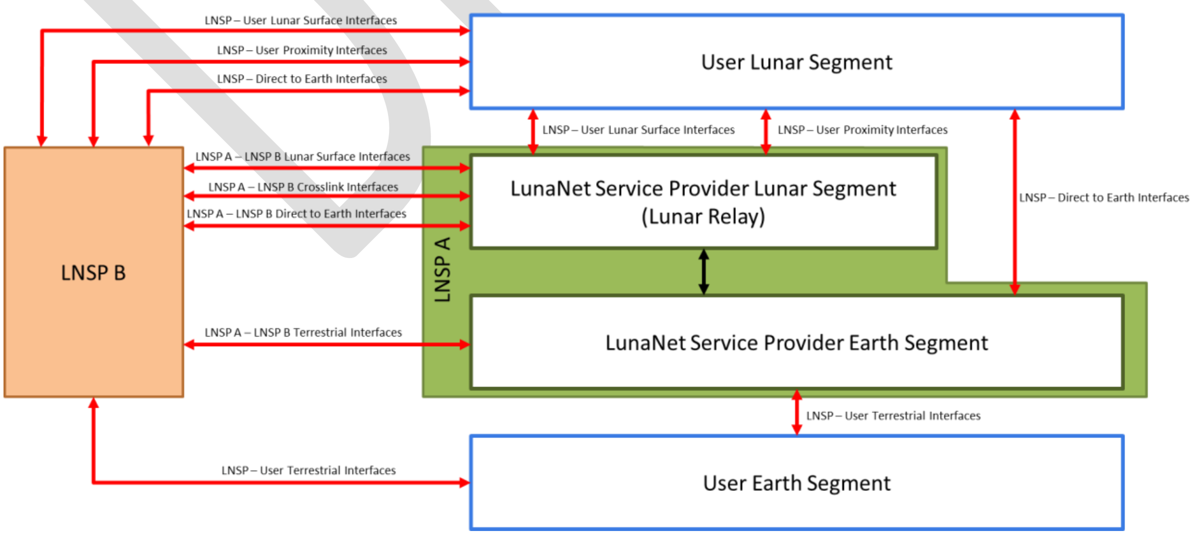

Figure 3 - LNSP Interfaces

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The LNSP interfaces are depicted in Figure 3. Each LNSP may have any combination of lunar surface, proximity, direct-to-Earth, and terrestrial interfaces with users. Interfaces between LNSPs may be any combination of lunar surface, crosslink, direct-to-Earth, and terrestrial interfaces. Lunar surface interfaces are interfaces between an LNSP lunar surface node and a user surface node. Proximity interfaces are between an LNSP lunar orbiting node and a user orbiting or surface node.

Table 1 - Lunar Network Service Provider Interfaces

Interface Name	Interface Description	Document Section
LNSP-User Lunar Surface Interfaces	Surface to surface interfaces between user and provider	4.1
LNSP-User Proximity Interfaces	User interfaces with lunar orbiting provider nodes	4.2
LNSP-User DTE Interfaces	Interfaces between user lunar systems and provider earth systems	4.3
LNSP-User Terrestrial Interfaces	Terrestrial interfaces between user and provider	4.4
LNSP A-LNSP B Lunar Surface Interfaces	Surface to surface interfaces between two LNSPs	6.1
LNSP A-LNSP B Crosslink Interfaces	Interfaces between two LNSP's lunar orbiting nodes	6.2
LNSP A-LNSP B DTE Interfaces	Interfaces between an LNSP lunar system and a different LNSP earth system	6.3
LNSP A-LNSP B Terrestrial Interfaces	Terrestrial interfaces between two LNSPs	6.4

This document identifies the standards to be used for the physical and service interfaces described above and depicted in red in Figure 3.

3. USER SERVICES

3.1 Communications Services

There are three communications service types (See Figure 4). Real-time data services provide end-to-end data delivery between source and destination with the minimum delay possible. The latency on these services will be due to the signal travel time, any channel coding, and data operations only. Store-and-forward data services provide end-to-end data delivery with additional latency incurred by storage of data along the end-to-end path. This storage allows for the delivery of data when discontinuities or significant rate buffering occurs along the path. Messaging services provide a means to send standardized messages from LunaNet applications over specified LunaNet message channels within communications services, while abstracting the specifics of those services from the messaging application.

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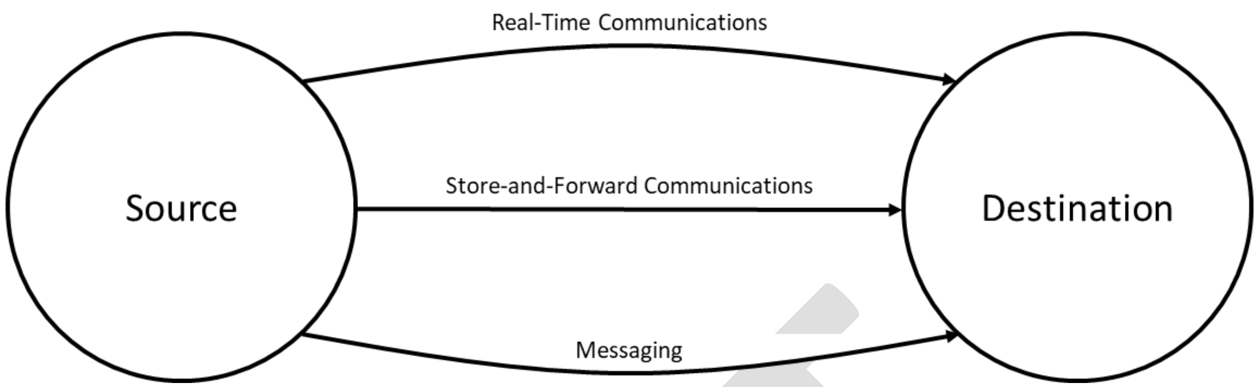

Figure 4 - Three Types of Communications Services

Figure 5 is a simplified view of the protocol stack options for LunaNet user applications. The applications are expected to be network-based using either the Delay/Disruption Tolerant Networking (DTN) Bundle Protocol (BP) or Internet Protocol (IP). However, a user application may use link layer service (dashed line) using Consultative Committee on Space Data Standards (CCSDS) Advanced Orbiting Systems (AOS) standard. The direct use of link layer service is intended for message service for LunaNet applications only and should be deprecated for user applications. Connections to a LunaNet access point over any available link will allow the user data to route to its destination. Though LunaNet will provide link layer services, network-based applications will allow for the evolution and scalability of both user and provider systems.

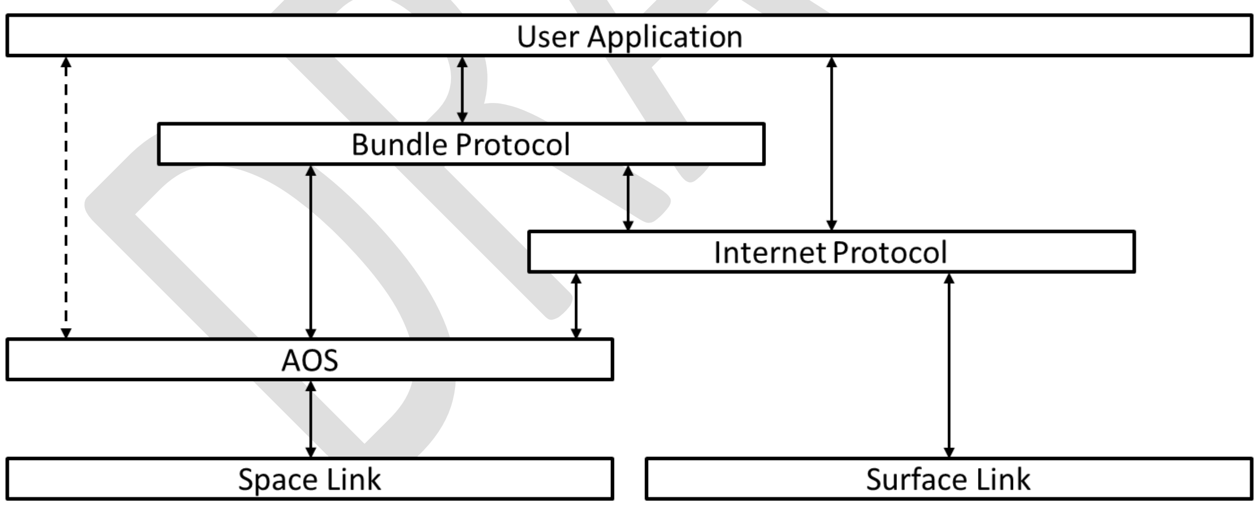

Figure 5 – User Application Simplified Protocol Stack

3.1.1 Real-Time Communications Services

Real-time communications services may be provided at both the link layer and the network layer.

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3.1.1.1 Real-Time Link Layer Communications Services

Link layer services will allow the relaying of data at the frame-level and requires no processing of user data within those frames. This may be required due to user link layer security or to enable higher speed operations. The link layer service may include the multiplexing, de-multiplexing, and forwarding of user data frames. For interoperability, the link layer services will require Consultative Committee for Space Data Systems (CCSDS) Advanced Orbiting Systems (AOS) frames. Because AOS frames are fixed length, future transition to a variable length frame standard is planned to simplify multiplexing and de-multiplexing data frames for users having different frame lengths. End-to-end delivery of data over a series of multiple links using link layer services will require pre-configuration of the full end-to-end path and is subject to interruption due to unplanned events.

3.1.1.2 Real-Time Network Layer Communications Services

Real-time network layer services provide end-to-end delivery of data over a series of multiple links with increased functionality and flexibility over the link layer services. The only network layer service guaranteed to provide end-to-end delivery to any network user is the DTN BP. However, operation assumptions for specific user applications will allow successful application support through real-time network layer services provided using the IP. Use of IP requires both source and destination to be operating within a portion of the network capable of supporting IP, such as the lunar surface. IP services are provided over AOS frames on the links described above or commercial standards, such as local wireless systems. Table 2 provides the summary of the IP service interfaces. Since DTN BP also provides the store-and-forward communications services, the interfaces for BP services are described by Table 3 in the following section.

Table 2 - IP Service Interfaces

Interface Name	Description	Applicable Interfaces	Applicable Documents
IP over CCSDS Encap/AOS	IP packets encapsulated using CCSDS Encapsulation Service and inserted into AOS frames	All AOS link layer service interfaces	CCSDS 702.1-B-1
IETF Standards	IP packets over current terrestrial standards	All terrestrial standard based interfaces	

3.1.2 Store-and-Forward Communications Services

Interoperable store-and-forward communications services will be provided using DTN BP. In the situations where an IP network can be used to connect one bundle node to the next, the DTN bundles can be carried within the IP services described in Section 3.1.1.2. For those cases when an IP network is not available, the DTN bundles are carried with AOS frames and the AOS link layer services described in Section 3.1.1.1. In all cases, convergence layer protocols are required between the bundles and the underlying AOS or IP service. Table 3 provides the summary of these options.

Table 3 - Bundle Protocol Service Interfaces

Interface Name	Description	Applicable Documents
TCPCL	TCP convergence layer used over IP networks	IETF RFC 7242[1]
UDPCL	UDP convergence layer used over IP networks	IETF RFC 7122[2]

LTP over Encap	Licklider Transmission Protocol over CCSDS Encapsulation Service	IETF RFC 5326 CCSDS 734.1-B-1
LTP over UDP	Licklider Transmission Protocol over UDP	IETF RFC 5326 CCSDS 734.1-B-1
Encap	CCSDS Encapsulation service	CCSDS 133.1-B-3

[1] RFC 7242: https://datatracker.ietf.org/doc/html/draft-ietf-dtn-tcpclv4-26

[2] RFC 7122: https://datatracker.ietf.org/doc/html/draft-sipos-dtn-udpcl-01

3.1.3 Messaging Services

Messaging services will provide a standard way for messages to be transferred directly over a link layer service or a network layer service. These messaging services will be utilized by LunaNet applications. LunaNet applications are applications for service acquisition, PNT, alerts, and other LunaNet services. These standard messages are to be employed across user links, provider crosslinks, as well as direct-to-Earth (DTE) links. Methods for carrying these messages over the other communications service are also standardized.

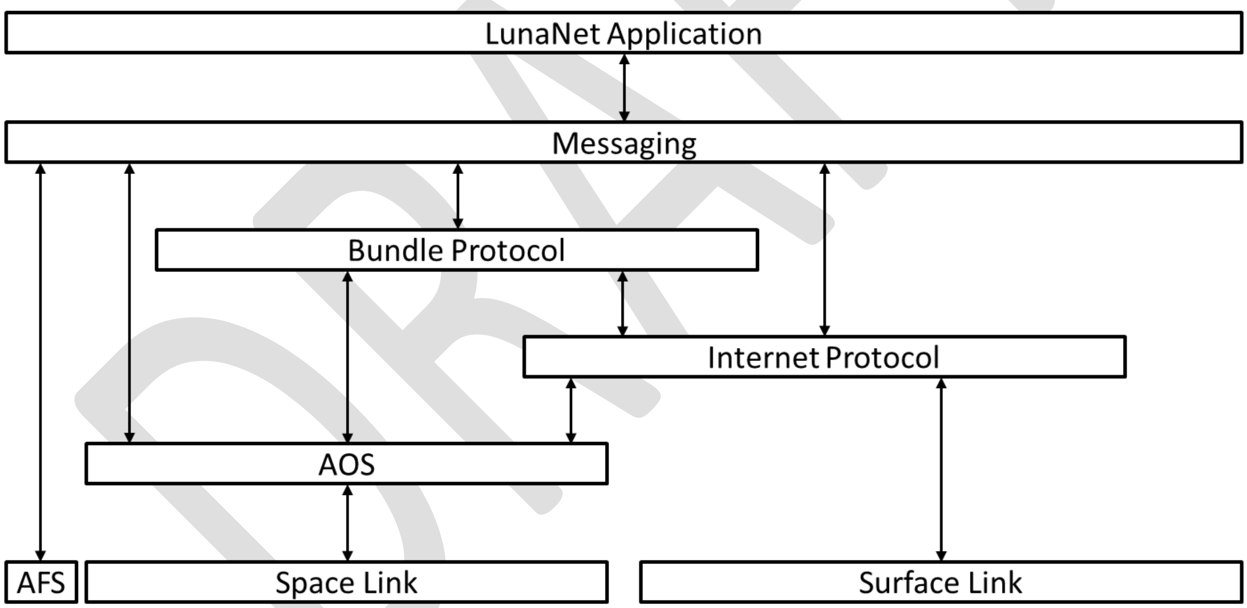

Figure 6 - LunaNet Applications Simplified Protocol Stack

Table 4 - Messaging Services Interfaces

Interface Name	Description	Applicable Documents
Message over Link	Messages inserted directly into AOS frames for transfer over a single link.	TBD
Message over IP	Messages inserted into IP packets to allow for multiple IP hops to IP destination.	TBD
Message over DTN	Messages inserted into DTN bundles to allow for multiple hops to any LunaNet destination.	TBD

Message over AFS	Messages transmitted over the Augmented Forward Signal (AFS) may be carried in a unique manner to accommodate the low AFS data rate.	TBD

Standardized protocols for PNT services, network acquisition, space weather alerts, search and rescue, etc. will define the specific messages for those functions. The messaging services are not intended for user data flows from applications other than LunaNet applications. The messaging services will provide methods for identifying message priorities. A publish and subscribe capability may be used for this service. The Augmented Forward Signal (AFS) link, described further later in this document, will carry messages differently than the other space links, due to the lower available data rate.

The specific standards for the messaging services are still being determined. Until the messaging services are in place, the LunaNet application messages will be transported along with the user application as depicted in Figure 5. In this case, the messages may be included in CCSDS space packets directly inserted into an AOS virtual channel. This is depicted by the dashed line in Figure 5.

3.2 Position, Navigation, and Timing Services

PNT services enable missions to determine position and velocity or surface location, plan trajectories, plan and execute maneuvers, and maintain time with accuracies and timeliness appropriate to meet mission requirements. PNT services require a combination of standardized signals for Doppler, ranging, timing, and standard messages and protocols for the exchange of measurements and products. These are needed for safety, situational awareness, communication, and mission and science objectives. To offer these services and provide interoperability, the intent is to take maximal advantage of the communication links through judicious signal structure definition. This can be accomplished in several ways. One method is to provide PNT through dedicated communication links with user. However, there is a need for lunar-global provisioning of PNT services to provide adequate geometry and appropriate time-to-first-fix to meet user requirements. Thus, a second method using an Augmented Forward Signal (AFS) provides PNT functionality independent of dedicated user communication links to enable multiple user reception of the signal simultaneously. Through the build-up of LunaNet nodes, this will lead to a Global Navigation Satellite System (GNSS)-like PNT capability for lunar PNT services.

The code division multiple access (CDMA) signal structure used for the Augmented Forward Signal (AFS) communication link can also be applied to dedicated proximity links. The difference will be in the selected frequency, while the integer number of pseudo-noise (PN) codes and chip rates remain unchanged for pseudorange and time purposes.

For communication links other than CDMA, with a known transmit frequency, the receiver could measure the Doppler shift on the carrier. Non-CDMA links supported by PN codes could provide an alternate method to derive pseudorange measurements beyond the traditional two-way methods with ground source and measurement. In addition, a method whereby a specific data frame at an integer modulo 1-second based on an accurate and stable time reference source can be used to provide pseudorange and time-transfer capability on these links.

For effective interoperability in the PNT domain, these signal structures for LunaNet providers and for LunaNet users must be defined, along with the implementation schemas for obtaining the measurements to ensure consistency in performance. Interoperability also relies on defining the formats, contents, transmission cadence, update rate, and prioritization for the messages for each signal type and service. Lastly, the LunaNet location service offered to users contains interoperability parameters to be defined.

Tables 5, 6, and 7 identify the PNT services including the messages required for interoperability. The specific service identifications listed in Tables 4-6 are explained in the subsections of 3.2 following the tables. The specifics of the messages will be defined in standard protocols used as part of the provision of the services, as will the specifications identified in Table 6 under "Required Interoperability Specifications."

PNT supporting messages include:

- **MSG-3 Health and Safety**: Defines health and safety parameters for a single craft.
- **MSG-5 Maneuver**: Singular craft maneuver parameters.
- **MSG-6 Observations**: Time-tagged sensor observations.
- **MSG-7 SOrbit State**: Singular orbit state for singular craft at one time epoch.
- **MSG-8 SOrbit Ephem**: Singular craft representation of a predictive orbit state over X period of time.
- **MSG-9 MOrbit State**: Singular orbit state for multiple craft at one time epoch.
- **MSG-10 MOrbit Ephem**: Multiple craft representation of predictive orbit states over X period of time.
- **MSG-11 SAttitude State**: Single attitude for singular craft.
- **MSG-12 SAttitude Ephem**: Singular craft representation of a predictive attitude state over X period of time.
- **MSG-13 Conjunction**: Parameters to advise of potential conjunctions.
- **MSG-14 Time and Frequency Synchronization (fine)**: Includes transmitter frequency and PN epoch at specified transmit time-tags and related time correction values to apply (e.g. time dilation parameters, transmitter system delays).
- **MSG-15 Time and Frequency Synchronization (frame)**: Includes transmitter frequency and time of message transmit and associated correction values to apply (e.g. time dilation parameters, transmitter system delays).
- **MSG-16 Map**: Digital Elevation map for a given sector, in support of TRN.
- **MSG-17 Ancillary Info**: Coordinate frame transformation, STM, Covariance, Lunar Reference Frame, etc.

[Note: Message (MSG) is abbreviated in the tables as "G" followed by the message ID number.]

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Table 5 - PNT Services and Required Interoperability Messages Provided by LunaNet

PNT Service ID	Services **Reference:** LunaNet Provider Transmits Signal **Measurement:** LunaNet Provider Measures and Sends to User **Transponds:** LunaNet Provider Coherently Transponds Signal from user [NOTE: Pseudo-Range means 1-way ranging.]	LunaNet Source Produced Messages						
		G3	G6	G7	G8	G11	G14 or G15	G5, G9, G10, G12, G13, G16, G17
		Relay H&S	Observable	Relay PVT	Relay Ephem	Relay Att	Tx Freq & Time Info	Supp
1wDRef	1-Way Doppler Reference	X		X	X	X	X	
1wRTRef	Pseudo-Range and Timing Reference	X		X	X	X	X	
1wDMeas	1-Way Doppler Measurement		X	X	X			
1wRTMeas	Pseudo-Range Measurement		X	X	X			
2wDMeas	2-Way Doppler Measurement		X	X	X			
2wRMeas	Range Measurement		X	X	X			
2wD-XPND	2-Way Coherent Doppler Transponder	X		X	X	X	X	
2wNRR-XPND	Non-Regenerative Range Transponder	X		X	X	X	X	
2wRR-XPND	Regenerative Range Transponder	X		X	X	X	X	
TRef	Time Transfer Reference	X		X	X	X	X	
Nav-G<x>	Supplemental Navigation Products							X
Loctn	Location Service	X	X	X	X	X		

Table 6 - PNT Services and Required Interoperability Messages Interpreted by LunaNet

PNT Service ID	Services **Reference:** LunaNet Provider Transmits Signal **Measurement:** LunaNet Provider Measures and Sends to User **Transponds:** LunaNet Provider Coherently Transponds Signal from user [NOTE: Pseudo-Range means 1-way ranging.]	Messages Interpreted by LunaNet						
		G3	G6	G7	G8	G11	G14 or G15	G5, G9, G10, G12, G13, G16, G17
		User H&S	Observable	User PVT	User Ephem	User Att	Tx Freq & Time Info	Supp
1wDRef	1-Way Doppler Reference							
1wRTRef	Pseudo-Range and Timing Reference							
1wDMeas	1-Way Doppler Measurement	X		X	X	X	X	
1wRTMeas	Pseudo-Range Measurement	X		X	X	X	X	
2wDMeas	2-Way Doppler Measurement			X	X	X	X	
2wRMeas	Range Measurement			X	X	X	X	
2wD-XPND	2-Way Coherent Doppler Transponder							
2wNRR-XPND	Non-Regenerative Range Transponder							
2wRR-XPND	Regenerative Range Transponder							
TRef	Time Transfer Reference							
Nav-G<x>	Supplemental Navigation Products							X
Loctn	Location Service		X	X	X		X	

Table 7 - PNT Services and Required Interoperability Specifications

PNT Service ID	Services **Reference:** LunaNet Provider Transmits Signal **Measurement:** LunaNet Provider Measures and Sends to User **Transponds:** LunaNet Provider Coherently Transponds Signal from user [NOTE: Pseudo-Range means 1-way ranging.]	Required Interoperability Specifications			
		LunaNet Signal Structure	LunaNet Measurement Schema and Parameters	User Signal Structure Definition	LunaNet Location Service for Users
1wDRef	1-Way Doppler Reference	X			
1wRTRef	Pseudo-Range and Timing Reference	X			
1wDMeas	1-Way Doppler Measurement		X	X	
1wRTMeas	Pseudo-Range Measurement		X	X	
2wDMeas	2-Way Doppler Measurement	X	X		
2wRMeas	Range Measurement	X	X		
2wD-XPND	2-Way Coherent Doppler Transponder			X	
2wNRR-XPND	Non-Regenerative Range Transponder			X	
2wRR-XPND	Regenerative Range Transponder			X	
TRef	Time Transfer Reference	X			
Nav-G<x>	Supplemental Navigation Products				
Loctn	Location Service	X	X	X	X

All PNT services described in Sections 3.2.1 through 03.2.4 require the LunaNet provider to have knowledge of its own PVT state, as well as future predicted values. This information is required to be forwarded to users for the consumption of the related services, in the form of messages G-7 and/or G-8, as indicated in Table 5.

The figures in the following sections use an arrow to indicate directionality associated with the notional image of a signal path.

3.2.1 Reference Signals

Communication links originating from a LunaNet node, as depicted in Figure 7, offer users the opportunity to derive measurements that describe the relative dynamics of the link. Defining the properties of each reference signal source enables users to derive pseudorange, timing, and one-way Doppler observables through their receiver system.

A combination of one-way observables and related messages from different LunaNet sources, or other observation types, are utilized by a user's in-situ navigation system to estimate the user's position, velocity (or surface location), and time.

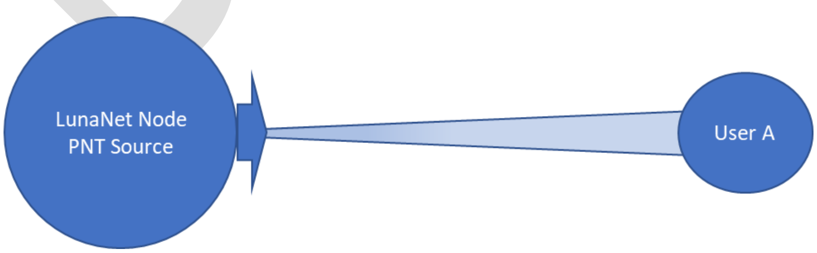

Figure 7 - Reference PNT Signals Provided by LunaNet Node

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3.2.1.1 One-Way Doppler Reference (1wDRef)

Most radio communication links may be employed for the purposes of obtaining one-way Doppler measurements by a user, provided the user has accurate knowledge of the center frequency employed by the source. This is best accomplished with the use of a fixed frequency transmission.

Differences in the measured frequency by the user will be due to Doppler, as well as frequency offsets from both the LunaNet and user's frequency reference sources. The LunaNet source conveys reference frequency value and deviations via message, as identified in Table 5.

3.2.1.2 Pseudo-Range and Timing Reference (1wRTRef)

The pseudo-range measurement approximates the distance between a LunaNet source and the user's receiver. The source emits a recognizable pattern at a given instant in time, which the user receives moments later, identifies, and timestamps.

Depending on the characteristics of the communication link, these patterns will take the form of pseudo-noise (PN) sequences or high-rate frame synchronization and identification (i.e., frame ranging). While the latter is a work in progress as of this writing, PN sequences have been employed in satellite ranging technologies for quite some time. PN codes as identified in CCSDS 414.1-B-2 and CCSDS 415.1-B-1 have traditionally been employed for two-way ranging purposes. To use them for one-way measurements, a method (TBD) must be set in place to convey information to the user correlating source PN phasing and the corresponding time of transmission. Similar to GNSS, PFS5 and PFS6 links as identified in Table 10 include PN sequences that repeat an integer number of times each second. This establishes a simple method for the LunaNet source to inform users of PN phasing and timing information.

Pseudo-range measurements will include errors due to source and receiver time reference offsets, unaccounted equipment delays on both ends and time dilution effects. Information concerning errors originating from the LunaNet source is provided to users via message (G14 or G15 from **Error! Reference source not found.**Table 5).

3.2.1.3 Time-Transfer Reference (Tref)

A standardized method (TBD) for a LunaNet node to provide a time reference will be implemented to allow users to have accurate time.

3.2.2 One-Way Measurements

One-way measurements performed by LunaNet nodes are in reverse fashion to what is described in section 3.2.1, as depicted in Figure 8. The users generate reference signals that enable LunaNet nodes to compute one-way Doppler and pseudo-range observables.

The resulting one-way measurement observables are forwarded to the necessary element via MSG-G6 messages, as identified in **Error! Reference source not found.**. These observables are used in combination with others by the designated navigation system to estimate the user's position, velocity, and time. The navigation system may be an in-situ navigation system, externally sourced or provided as a LunaNet service as described in section 3.2.6.

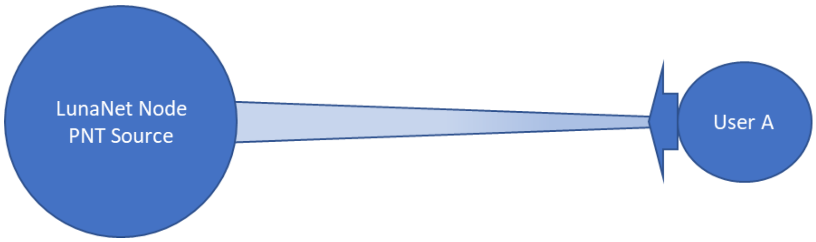

Figure 8 - One-Way Measurements Performed by LunaNet Node

3.2.2.1 One-Way Doppler Measurement (1wDMeas)

One-way Doppler measurements may be carried out for most incoming radio-communication signals by tracking the frequency of the received signal and reporting the delta with respect to a defined reference frequency. These measurements become valuable when the original frequency transmitted by the user is accurately determined and communicated to the LunaNet measuring system. Users employ messages, as identified in **Error! Reference source not found.**, to convey reference frequency values and deviations.

The quality of the measurement will mainly depend on the stability of the user's frequency source, as well as the signal-to-noise ratios of the received signal. Errors due to frequency offsets between user and LunaNet frequency references may be estimated by the corresponding navigation system. This is facilitated by the exchange of reference frequency values and deviations via messages between user sources and LunaNet measurement systems, as identified in **Error! Reference source not found.** and **Error! Reference source not found.**.

3.2.2.2 Pseudo-Range Measurement (1wRTMeas)

The pseudo-range measurement is as described in section 3.2.1.2, though in reverse fashion. The user generates a reference signal that is utilized by the measuring LunaNet system to obtain a pseudo-range observable.

The LunaNet system must be compatible with, and knowledgeable of, the ranging signal characteristics employed by the user as indicated in Table 6 - User Signal Structure Definition interoperability specification.

Pseudo-range measurements will include errors due to source and receiver time reference offsets, and unaccounted phase delays and time corrections beyond what can be determined. The LunaNet measurement system interprets information concerning these errors originating on the user end via user-provided messages, MSG-G14 or MSG-G15, as indicated in **Error! Reference source not found.**. Corrections applied by the LunaNet measurement system are to be included in the corresponding observation messages, MSG-6 as indicated in **Error! Reference source not found.**.

3.2.3 Two-Way Measurements

Two-way measurements performed by LunaNet are similar to two-way radiometric services historically provided by the different tracking networks, where the tracking stations compare the transmitted and received signals to derive Doppler and round-trip-delay observations. Generally, these measurements require users to return a signal that is coherently related to the signal they receive from the stations, as illustrated in Figure 9 below. Range measurements can be supported by non-coherent two-way communication interfaces, by means of frame ranging as described in section 3.2.3.2 below.

Figure 9 - Two-Way Measurements Performed by LunaNet Node

Two-way measurement observations are disseminated to the required element via MSG-6 messages, as indicated in **Error! Reference source not found.**.

3.2.3.1 Two-Way Doppler Measurement (2wDMeas)

Two-way Doppler measurements require LunaNet to determine the differences in phase between transmitted and received signal center frequencies, at predetermined time intervals. The user must coherently transpond the received frequency from LunaNet by implementing a predefined turn-around ratio.

3.2.3.2 Range Measurement (2wRMeas)

The range measurements performed by LunaNet can be separated into three categories: non-regenerative, regenerative, and frame ranging.

Non-regenerative ranging (a.k.a. transparent ranging) involves the user filtering and re-modulating the ranging signal onto the return signal. This method does not require the user to have prior knowledge of the ranging signal utilized for the service, only the frequency bandwidth allocated to it. The PN ranging signals described in CCSDS 414.1-B-2 may be used for this purpose.

Regenerative ranging involves PN code acquisition by the user and the return of a synchronized return PN ranging signal. It offers the benefit of reducing the amount of noise present in the measurement, resulting in higher accuracies. The PN ranging signals described in CCSDS 415.1-B-1 and CCSDS 414.1-B-2 may be used for this purpose, in addition to the signal structure defined in Appendix C.

Frame ranging involves timestamping and identification of synchronized information frames. It is particularly useful in high-rate communication links, where elevated data frame rates facilitate more accurate time resolution. A frame ranging standard is TBD.

3.2.4 Two-Way Transponder

Two-way transponder services support a similar process as described in Section 3.2.3, with the LunaNet and user roles reversed. Users capable of performing two-way measurements require the LunaNet provider to send the signal back to them, as depicted in Figure 10.

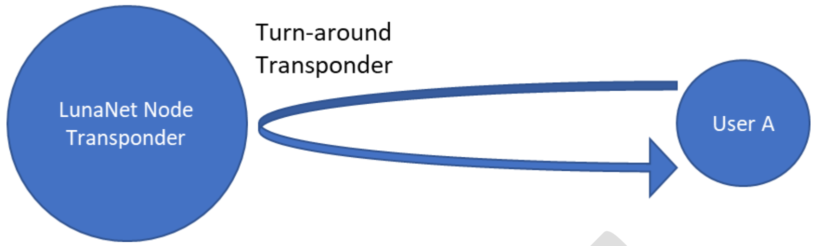

Figure 10 - Two-Way LunaNet Node Transponder

3.2.4.1 Two-Way Coherent Doppler Transponder (2wD-XPND)

In support of user two-way Doppler measurements, the LunaNet element coherently relates the forward frequency to the return frequency received from the user. The turn-around ratios applied by LunaNet are the inverse of the ratios employed by user transponders, in order to maintain the frequency allocations assigned.

3.2.4.2 Non-Regenerative Range Transponder (2wNRR-XPND)

In addition to what is performed for the two-way Doppler transponder service, a non-regenerative LunaNet transponder filters and re-modulates the ranging signal onto the forward signal. The LunaNet provider does not require knowledge of the ranging signal type employed by the user. The bandwidth allocated to the ranging signal and used by the LunaNet provider for filtering shall be <TBD>.

3.2.4.3 Regenerative Range Transponder (2wRR-XPND)

The regenerative ranging transponder service involves PN code acquisition by the LunaNet provider, followed by the transmission of a synchronized forward PN ranging signal.

The PN ranging signals described in CCSDS 415.1-B-1 and CCSDS 414.1-B-2 may be used for this purpose, in addition to the signal structure defined in Appendix C.

3.2.5 Supplemental Navigation Products (Nav-G<x>)

Additional navigation products are embedded in standardized messages to allow exchange between network elements of in-situ navigation-enabling and PNT-related information, as identified in **Error! Reference source not found.**, **Error! Reference source not found.** and Table 7.

3.2.6 Location Service (Loctn)

The LunaNet provider capable of carrying out location services receives observations from multiple sources via MSG-G6 type messages. MSG-G7 or MSG-G8 and MSG-G1 may be a needed supplement if measurements were obtained by other LunaNet assets. These observations are routed to the navigation system responsible for deriving the user's position, velocity, and time knowledge. A request for location services includes necessary information for performing location or orbit determination for a specific user.

Location service products are disseminated by means of MSG-G7 and/or MSG-G8 messages.

3.3 Detection and Information Services

Detection and information services include LunaNet applications within the network infrastructure to support alerts and other critical information to support user operations. Examples include space weather alerts triggered by instrumentation within provider systems and Lunar Search and Rescue (LunaSAR) beacon detection/location. These applications would generate and transmit messages using the formats and interfaces described in Appendix C. These services would have standard messages specific to their functions, such that all receiving the messages will be able to understand them. The messages would be communicated using the messaging services described in 3.1.3.

Table 8 - Detection and Information Services

Service	Description	Required Interop Standards
Lunar Search and Rescue (LunaSAR)	Determines user location and gathers critical user status	• LunaSAR Message Content / Format • Distress Message Prioritization • Possible signal design
Space Weather	Alerts and other relevant information concerning Space Weather	• Space Weather Messages

3.3.1 Lunar Search and Rescue (LunaSAR) Services

Lunar Search and Rescue (LunaSAR) services enable users to report location and distress information via internationally recognized messaging standards modelled after current state-of-the-art messaging content used in terrestrial search and rescue (SAR) activities. LunaSAR services require a combination of reception, prioritization, and re-broadcast/pass-through of distress messages on the LunaNet DTE and proximity links. LunaSAR message content is defined via inputs from the extravehicular activity (EVA) user community and SAR best practices. LunaSAR services are envisioned as an EOC capability. LunaSAR messages leverage rotating field definitions to reduce message size, allowing for robust low-data rate message transmissions from disadvantaged users to the LunaNet constellation at low power requirements and constrained link-budgets.

LunaSAR services include location reporting of distress information, and low-data-rate bi-directional messaging between LunaSAR beacon users and message recipients such as Earth-based mission controllers, lunar surface assets, and lunar encampments.

LunaSAR services occur over the PFS6 [TBR] and PRS6 [TBR] links and are prioritized for rebroadcast when received by the LunaNet orbiting asset(s). Prioritization aligns with the principles of terrestrial

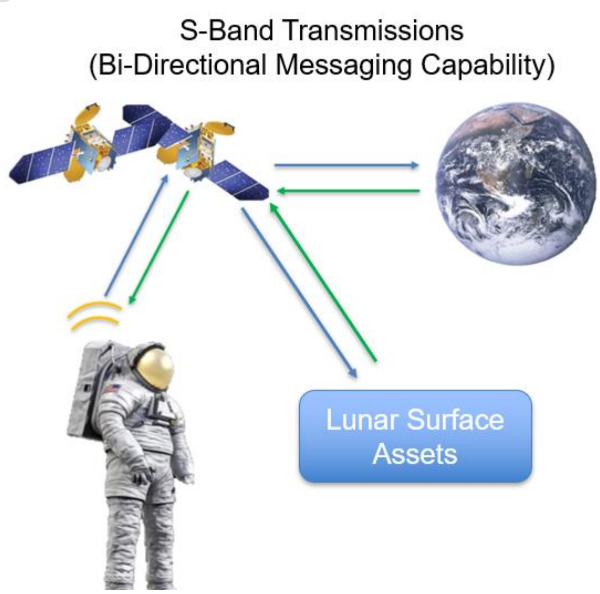

Figure 11 - LunaSAR Data Path Conops

distress tracking services commercially available to those engaged in dangerous activities. LunaSAR messages are notionally formatted in Concise Binary Object Representation (CBOR) formatting to allow for increased processing and transfer speeds between LunaSAR users and LunaNet users. Note that rotating field messages as described in this section are for example only and can be tailored to the specific lunar distress application/end-user hardware development. For example, message content would be derived from telemetry streams that could be monitored for faults (i.e., space suit pressure issue, radiation exposure, etc.) and trigger automated distress message generation. This process mimics current International Maritime Organization (IMO) and International Civil Aviation Organization (ICAO) provisions for automated distress tracking and notification services, to be replicated as applicable within the lunar domain in the EOC phase.

LunaSAR service broadcasts begin upon manual or automated triggering of distress transmissions and do not broadcast unless required. This aligns with the terrestrial standard for Cospas-Sarsat beacons and serves to preserve the nominal bandwidth within the relay system. Repetition rates following beacon/distress mode activation are detailed in a separate document (TBD).

3.3.2 Space Weather Alerting Services

Space Weather alerts and related messages will be communicated using the messaging services. The specific standard alert and message content are still TBD. Initiation of weather alerts could be native to the LunaNet node in lunar orbit if suitable instrumentation is present, or it could be received from another asset (space or Earth) and relayed accordingly to users in lunar proximity.

3.4 Science Services

LunaNet assets may be able to support science objectives through use of available radio/optical links and telemetry. Some science services may only require that LunaNet space equipment operate in a special mode within the capabilities of the communication and PNT subsystem. These services may require standardized message formats to collect and share measurements from the variety of possible LunaNet systems.

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3.5 Service Access

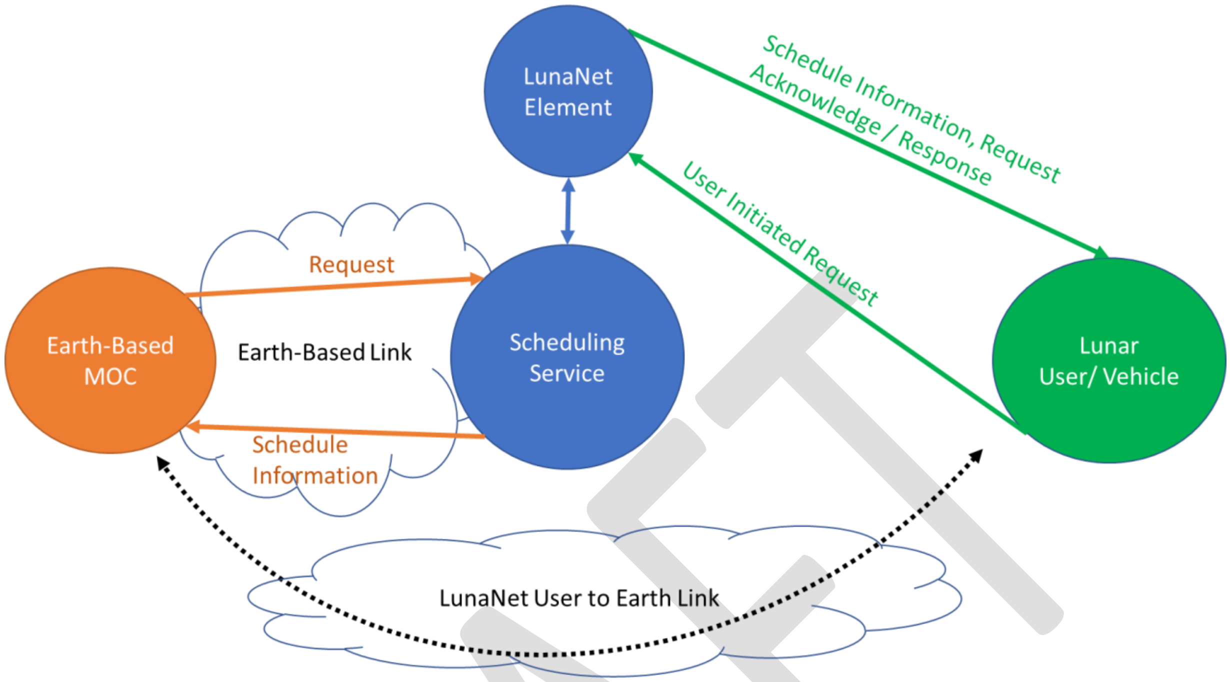

Figure 12 - LunaNet Scheduling Interfaces Overview

Users will be able to access services through a variety of methods (See Figure 12). Services may be scheduled through an LNSP's Scheduling Service that allows a mission operations center to pre-schedule services with a network provider. Users that employ the services of more than one LNSP must schedule service separately with each LNSP and maintain their mission-specific combined schedule. Standardized methods for allowing one LNSP schedule services with another LNSP on behalf of a user are desired. Multiple Access Links will allow users to receive services immediately without any scheduling. User Initiated Services will allow user platforms to request and receive services over links between the user platform and a LunaNet provider node.

3.5.1 Earth-based Scheduling Service

Each LunaNet service provider may have their own unique interface for Earth-based schedule requests. No standards for this interface have been identified yet.

3.5.2 Multiple Access Links

3.5.2.1 Multiple Access Forward Link/Augmented Forward Signal (AFS) Service

A multiple access forward link will be implemented using the AFS design. The signal represented as PFS5 in the LNSP-User Proximity Interfaces and further described in Appendix C will provide communication and navigation functions simultaneously to multiple users in the lunar region, without the need for a user

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to establish dedicated proximity links with a particular LunaNet element. A single frequency will be used for the AFS signal and systems will be optimized to maximize coverage and availability for users. This optimization will likely lead to a lower available data rate, so the AFS data will be restricted to LunaNet application messages.

The AFS serves as an entry point to the LunaNet network. Users entering the service volume acquire the AFS signal and obtain a coarse state of services available. This service enables LunaNet to provide users with contact information, schedule, availability, and position of different LunaNet elements, and acknowledgement of user requests or receipt of messages. Given the ubiquitous nature of the service, it serves as a dissemination channel for relevant notifications and alerts via provision of standard messages. The AFS will also provide the PNT services as described in 3.2.

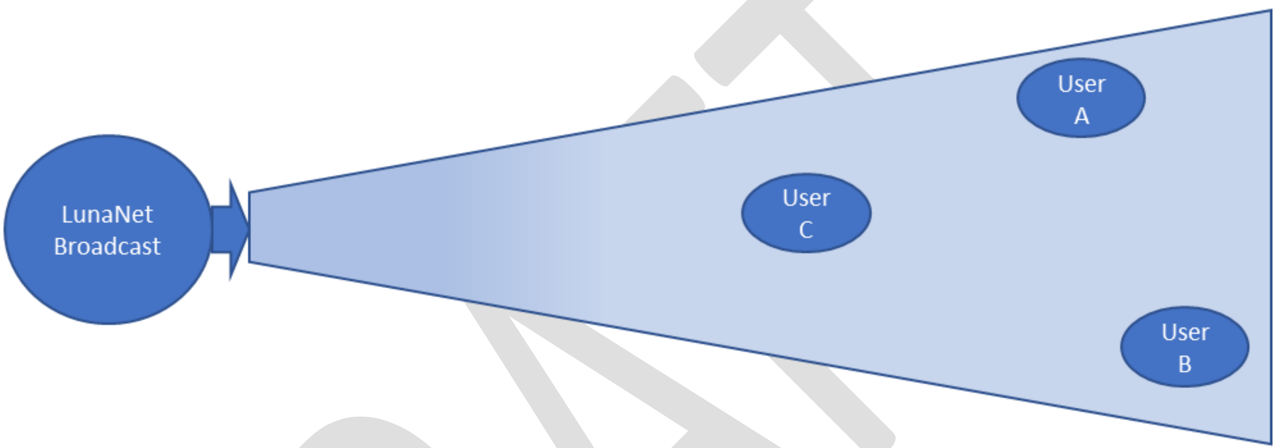

Figure 13 - Augmented Forward Signal Service Provided by a Single LunaNet Source

Refer to Appendix C for AFS signal structure definition and message requirements.

3.5.2.2 Multiple Access Return Link

The multiple access return link provides users with a highly available interface to initiate service requests, forward situational awareness messages, or send search and rescue alerts to the LunaNet network. This may also be used for lower rate user telemetry and science data.

Refer to Appendix C for AFS signal structure definition and message requirements. The PRS5 CDMA signal design will support simultaneous links from multiple users and the PNT functions described in 3.2.

3.5.2.3 User Initiated Services

User Initiated Services may be implemented through service acquisition protocols incorporating messages utilizing the messaging services or through a hailing approach similar to the CCSDS Proximity 1 protocol. Standards for both of these approaches are yet TBD.

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4. LUNANET SERVICE PROVIDER TO USER INTERFACES

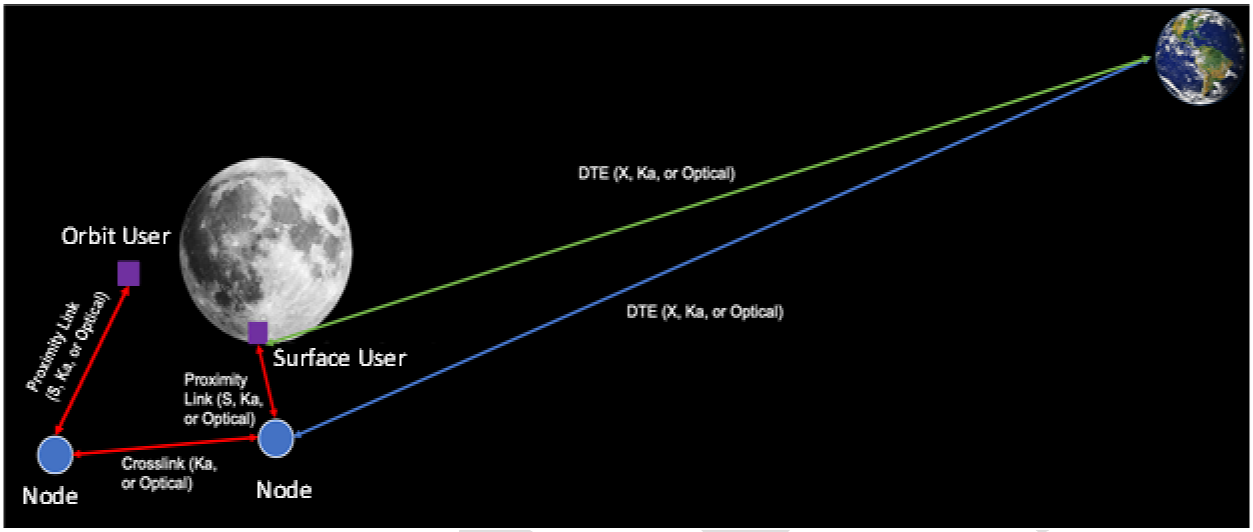

Figure 14 - Functional interfaces and corresponding frequency bands

The functional interfaces and corresponding frequency bands for the lunar radio frequency links are shown in the following sections. Allowable signal bandwidths and power levels will be determined through the spectrum management process. Standards for optical link interfaces are TBD.

4.1 LNSP-User Lunar Surface Interfaces

Table 9 summarizes the lunar surface-surface link layer service interfaces.

Table 9 - LNSP–User Lunar Surface-Surface Link Layer Service Interfaces

Interface name	Interface Type	Description	Targeted Frequency Range	Applicable Documents
LS1	Short-range wireless network	Wi-Fi 6, Wi-Fi Certified AC	5.150-5.895 GHz (Lunar Near-side use only)(TBR)	CCSDS 883.0-B-1[1]
LS2	Short-range wireless network	Wi-Fi 6, Wi-Fi Certified N	2.4-2.4835 GHz	CCSDS 883.0-B-1[1]
LS3	Short-to-medium range wireless network with mobility and roaming	3GPP rel. 12 (and higher)	TBD	CCSDS 883.0-B-1[1]

[1] CCSDS 883.0-B-1 publication expected fall 2021; currently in review as CCSDS 883.0-R-1.

[2] This band identified has not been approved by SFCG for Lunar region/surface applications.

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[3] The exact frequency channel(s) have not been determined and are subject to coordination.

4.2 LNSP-User Proximity Interfaces

Table 10 provides a summary of the different interfaces for transmitting AOS frames across proximity links. PFS5 and PRS5 are designed to allow for the implementation of one-to-many interfaces, such as a forward link broadcast and a user to multiple provider return.

Table 10 - LNSP–User Proximity Link Layer Service Interfaces

Interface Name	Interface Type	Targeted Frequency Range	Modulation	Coding	Frame Size	Applicable Documents
		Note: exactly center frequency to be determined based on user requirements, conops, and are subject to coordination.				
PFS1	Proximity Forward S-Band Link	2025-2110 MHz	Filtered BPSK/BPSK + NRZ-L	LDPC rate 1/2 (4096 octets plus 64 bit ASM) or uncoded (2048 octets plus 32 bit ASM)	AOS, frame size 2048 octets	CCSDS 401.0-B-31 CCSDS 131.0-B-3
PFS2	Proximity Forward S-band Link	2025-2110 MHz	SS-BPSK CDMA (~3Mcps)	LDPC (rates TBD)	AOS, frame size 2048 octets	CCSDS 415.1-B-1 CCSDS 131.0-B-3
PFS5	Proximity Forward S-band Link	(TBD)	SS-BPSK CDMA (~4Mcps)	LDPC (rates TBD)	AOS, frame size 2048 octets	CCSDS 415.1-B-1[1]
PFS6	Proximity Forward S-band Link	2025-2110 MHz	SS-BPSK CDMA (~4Mcps)	LDPC (rates TBD)	AOS, frame size 2048 octets	CCSDS 415.1-B-1[1]
PRS1	Proximity Return S-Band Link	2200-2290 MHz	Filtered BPSK/BPSK + NRZ-L	LDPC rate 1/2 (4096 octets plus 64 bit ASM) or uncoded (2048 octets plus 32 bit ASM)	AOS, frame size 2048 octets	CCSDS 401.0-B-31 CCSDS 131.0-B-3
PRS2	Proximity Return S-band Link	2200-2290 MHz	SS-BPSK CDMA (~3Mcps)	LDPC (rates TBD)	AOS, frame size 2048 octets	CCSDS 415.1-B-1 CCSDS 131.0-B-3
PRS5	Proximity Return S-band Link	(TBD)	SS-BPSK CDMA (~4Mcps)	LDPC (rates TBD)	AOS, frame size 2048 octets	CCSDS 415.1-B-1[2]

PRS6	Proximity Return S-band Link	2200-2290 MHz	SS-BPSK CDMA (~4Mcps)	LDPC (rates TBD)	AOS, frame size 2048 octets	CCSDS 415.1-B-1[2]
PFKa1	Proximity Forward Ka-Band Link	23.15-23.55 GHz (TBR)	Filtered OQPSK	LDPC rate 7/8 (1020 octets plus 32 bit ASM) or uncoded (2048 octets plus 32 bit ASM)	AOS, frame size 892 octets (LDPC rate 7/8) or 2048 octets (uncoded)	CCSDS 401.0-B-31 CCSDS 131.0-B-3
PFKa2	Proximity Forward Ka-Band Link	23.15-23.55 GHz (TBR)	Filtered OQPSK/ GMSK (Modulation on suppressed carrier)	Convolutional Code CCSDS VCM (DVB-S2, SCCC, or LDPC-VCM) to be selected for higher rates and higher coding performance	AOS, frame size 892 octets (LDPC rate 7/8) or 2048 octets (uncoded)	CCSDS 131.0-B-3 CCSDS 131.2-B-1
PRKa1	Proximity Return Ka-Band Link	27.0-27.5 GHz (TBR)	Filtered OQPSK	LDPC rate 7/8 (1020 octets plus 32 bit ASM) or uncoded (2048 octets plus 32 bit ASM)	AOS, frame size 892 octets (LDPC rate 7/8) or 2048 octets (uncoded)	CCSDS 131.0-B-3 CCSDS 131.2-B-1
PRKa2	Proximity Return Ka-Band Link	27.0-27.5 GHz (TBR)	Filtered OQPSK/ GMSK (Modulation on suppressed carrier)	Convolutional Code CCSDS VCM (DVB-S2, SCCC, or LDPC-VCM) to be selected for higher rates and higher coding performance	AOS, frame size 892 octets (LDPC rate 7/8) or 2048 octets (uncoded)	CCSDS 131.0-B-3 CCSDS 131.2-B-1

[1] PFS5 and PFS6 PN Code chipping rate and PN code length may differ from CCSDS 415.1-B-1. The CCSDS standard identifies approximately 3 Mcps and $(2^{10}-1) \times 256$, respectively for rate and length. PFS5 identifies approximately 4 Mcps and $2^{14}-1$, respectively for rate and length, both TBD.

[2] PRS5 and PRS6 PN Code chipping rate and PN code length may differ from CCSDS 415.1-B-1. The CCSDS standard identifies approximately 3 Mcps and $(2^{10}-1) \times 256$, respectively for rate and length. PRS5 identifies approximately 4 Mcps and $2^{14}-1$, respectively for rate and length, both TBD.

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4.3 LNSP-User DTE Interfaces

Table 11 - LNSP–User Direct to Earth Link Layer Service Interfaces

Interface Name	Interface Type	Targeted Frequency Range	Modulation	Coding	Applicable Documents
		Note: exactly center frequency to be determined based on user requirements, conops, and are subject to coordination.			
XU1	X-band Uplink	7190-7235 MHz	PCM/PM/bi-phase-L (Modulation on residual carrier) with PN ranging	LDPC	CCSDS 401.0-B-31 CCSDS 131.0-B-3 CCSDS 414.1-B-2
XU2	X-band Uplink	7190-7235 MHz	GMSK with PN ranging	LDPC	CCSDS 401.0-B-31 CCSDS 131.0-B-3 CCSDS 414.1-B-2
XD1	X-band Downlink	8450-8500 MHz	PCM/PM/bi-phase-L (Modulation on residual carrier) with PN ranging	LDPC	CCSDS 401.0-B-31 CCSDS 131.0-B-3 CCSDS 414.1-B-2
XD2	X-band Downlink	8450-8500 MHz	GMSK with PN ranging	LDPC	CCSDS 401.0-B-31 CCSDS 131.0-B-3 CCSDS 414.1-B-2
KaU1	Ka-Band Uplink	22.55-23.15 GHz	Filtered OQPSK/ GMSK (Modulation on suppressed carrier) with frame ranging	LDPC	CCSDS 401.0-B-31 CCSDS 131.0-B-3
KaD1	Ka-Band Downlink	25.5-27.0 GHz	Filtered OQPSK/ GMSK (Modulation on suppressed carrier) with frame ranging	LDPC	CCSDS 401.0-B-31 CCSDS 131.0-B-3

4.4 LNSP-User Terrestrial Interfaces

Table 12 - LNSP–User Terrestrial Link Layer Service Interfaces

Service Interface ID	Interface Type	Applicable Documents
SLE RAF	Space Link Extension Return All Frames	CCSDS 911.1-B-4
SLE RCF	Space Link Extension Return Channel Frames	CCSDS 911.2-B-3
SLE FCLTU	Space Link Extension Forward CLTU	CCSDS 912.1-B-4
SLE FFS	Space Link Extension Forward Frame Service	CCSDS 922.3-R-1

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5. LUNANET SERVICE PROVIDER TO LUNANET SERVICE PROVIDER SERVICES

5.1 LNSP A-LNSP B Communications Services

Using standard interfaces, an LNSP will be able to provide the communications services described in section 3.1. This will enable LunaNet communications service infrastructure to be provided by multiple providers. Beyond the user data, there will be communications between LNSPs for scheduling, routing, asset availability, and other functions.

5.2 LNSP A-LNSP B PNT Services

PNT Services, as described in section 3.2 Position, Navigation, and Timing Services, may also be provided between assets belonging to two different LNSPs.

6. LUNANET SERVICE PROVIDER TO LUNANET SERVICE PROVIDER INTERFACES

6.1 LNSP A-LNSP B Lunar Surface Interfaces

These interfaces will follow the same standards as identified in section 4.1 LNSP-User Lunar Surface Interfaces.

6.2 LNSP A-LNSP B Crosslink Interfaces

Crosslinks will allow two LNSPs to pass user data between their assets, message between the assets, and provide PNT services.

LunaNet providers will be required to directly exchange information within the internal architecture, independently from DTE interfaces, to enable awareness of the overall service health, availability and status, current and future schedule, time synchronization, as well as use of observables for self-navigation purposes. This section covers required interfaces between providers in order to ensure resilient services independent from Earth links. These crosslinks are to be carefully designed such that they are compatible with user links (TBD).

Table 13 - LNSP–LNSP Crosslink Layer Interfaces

Interface Name	Interface Type	Targeted Frequency Range	Modulation	Coding	Applicable Documents
		Note: exactly center frequency to be determined based on user requirements, conops, and are subject to coordination.			
CFKa1	Crosslink Forward	23.15 – 23.55 GHz (TBD)			

CRKa1	Crosslink Return	27.00 – 27.50 GHz (TBD)			

6.3 LNSP A-LNSP B DTE Interfaces

These interfaces will follow the same standards as identified in 4.3 LNSP-User DTE Interfaces.

6.4 LNSP A-LNSP B Terrestrial Interfaces

These interfaces will follow the same standards as identified in section 4.4 LNSP-User Terrestrial Interfaces.

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Appendix A. **LunaNet Interoperability Specification Phase Allocations**

Table A-1 Phase Allocations

Section	Name	IOC	EOC
3.1.1.1	Real-Time Link Layer Communications Services	X	X
3.1.1.2	Real-Time Network Layer Communications Services	X	X
3.1.2	Store-and-Forward Communications Services	X	X
3.1.3	Messaging Services	X	X
3.2.1.1	One-Way Doppler Reference (1wDRef)	X	X
3.2.1.2	Pseudo-Range and Timing Reference (1wRTRef)	X	X
3.2.1.3	Time-Transfer Reference (Tref)	X	X
3.2.2.1	One-Way Doppler Measurement (1wDMeas)		X
3.2.2.2	Pseudo-Range Measurement (1wRTMeas)		X
3.2.3.1	Two-Way Doppler Measurement (2wDMeas)	X	X
3.2.3.2	Range Measurement (2wRMeas)	X	X
3.2.4.1	Two-Way Coherent Doppler Transponder (2wD-XPND)		X
3.2.4.2	Non-Regenerative Range Transponder (2wNRR-XPND)		X
3.2.4.3	Regenerative Range Transponder (2wRR-XPND)		X
3.2.5	Supplemental Navigation Products (Nav-G<x>)	X	X
3.2.6	Location Service (Loctn)		X
3.3.1	Lunar Search and Rescue (LunaSAR) Services		X
3.3.2	Space Weather Alerting Services		X
3.4	Science Services		X
3.5.1	Earth-Based Scheduling Interface	X	X
3.5.2	Multiple Access Links	X	X
3.5.3	User Initiated Services		X
4.1	LNSP-User Lunar Surface Interfaces	X	X
4.2	LNSP-User Proximity Interfaces (PFS1, PFS5, PRS1, PRS5, PFKa1, PRKa1 only)	X	X
4.2	LNSP-User Proximity Interfaces		X
4.3	LNSP-User DTE Interfaces (XU1, XD1, KaU1, KaD1 only)	X	X
4.3	LNSP-User DTE Interfaces		X
4.4	LNSP-User Terrestrial Interfaces	X	X
5.1	LNSP A-LNSP B Communications Services	X	X
5.2	LNSP A-LNSP B PNT Services	X	X
6.1	LNSP A-LNSP B Lunar Surface Interfaces		X
6.2	LNSP A-LNSP B Crosslink Interfaces		X
6.3	LNSP A-LNSP B DTE Interfaces	X	X
6.4	LNSP A-LNSP B Terrestrial Interfaces	X	X

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Appendix B. Acronyms and Abbreviations

Table B-1 Acronyms and Abbreviations

Acronym	Description
3GPP	3rd Generation Partnership Project
AFS	Augmented Forward Signal
AOS	Advanced Orbiting Systems
ASM	Attached Sync Marker
BP	Bundle Protocol
BPSK	Binary Phase Shift Key
CBOR	Concise Binary Object Representation
CLPS	Commercial Lunar Payload Services
CCSDS	Consultative Committee for Space Data Systems
CDMA	Code Division Multiple Access
CLTU	Command Link Transmission Unit
DTE	Direct to Earth
DTN	Delay/Disruption Tolerant Networking
DVB-S2	Digital Video Broadcasting-Second Generation
EOC	Early Operational Capability
ESC	Exploration and Space Communication
EVA	Extravehicular Activity
GMSK	Gaussian Minimum Shift Keying
GNSS	Global Navigation Satellite System
ICAO	International Civil Aviation Organization
ICMP	Information and Configuration Management Plan
IETF	Internet Engineering Task Force
IMO	International Maritime Organization
IOC	Initial Operational Concept

IP	Internet Protocol
LDPC	Low Density Parity Check
LNS	LunaNet System
LNSP	LunaNet Service Providers
LTP	Licklider Transmission Protocol
MOC	Mission Operations Center
NPD	NASA Policy Directives
NPR	NASA Procedural Requirements
NRZ-L	Nonreturn-To-Zero Level
NTP	Netrix Trunk Protocol
OQPSK	Offset Quadrature Phase Shift Keying
P2P	Point to Point
PN	Pseudo-Noise
PNT	Position, Navigation, Timing
PVT	Position, Velocity, Timing
RF	Radio Frequency
RFC	Radio Frequency Compatibility
SAR	Search and Rescue
SCaN	Space Communications and Navigation
SCCC	Spacecraft Command and Control Center
SS-BPSK	Spread Spectrum Binary Phase-Shift Keying
TBD	To Be Determined
TCP/IP	Transmission Control Protocol/Internet Protocol
UDP	User Datagram Protocol
VCM	Variable Coding and Modulation
WiFi	Wireless Fidelity

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Appendix C. **Detailed Signal Definitions**

PFS 5/6 Signal Definition

The PFS5/PFS6 signal design enables simultaneous communication and navigation capabilities. These links can provide rates of up to 400 ksps (TBC). In terms of navigation, the signals support Doppler (1-way or 2-way), range, pseudorange and accurate time-transfer. The constant chip rate and integer number of PN codes per second facilitate pseudorange and time-transfer, as PN phasing at any instant in time is relatively straight-forward to determine and convey. Refer to Table C-1 for specific signal characteristics.

Table C-1 - LunaNet PFS5/6 Signal Characteristics

Parameter	Value
Signal Type	CCSDS 415.1-B-1 (modified), suppressed carrier, CDMA, SS-BPSK
PN Chip Rate	4.095750 Mcps
PN Code	Gold Codes, PN14 with length 16383
PN Periodicity	250 sequences/second
Range Ambiguity	~1200 km
Range Measurement Accuracy	< ~ +/-0.747 m
Bandwidth	8 MHz TBC
Symbol Rate	<=400 ksps TBC, ~1 ksps for PFS5 (AFS) due to MAI (TBC)

Table C-2 - LunaNet PFS5/6 Frequency Alternatives

Multiplier (x 4.09575 MHz)	Frequency (MHz)
~~495~~	~~2027.396250~~
496	2031.492000
497	2035.587750
498	2039.683500
499	2043.779250
500	2047.875000
501	2051.970750
502	2056.066500
503	2060.162250
504	2064.258000
505	2068.353750
506	2072.449500
507	2076.545250
508	2080.641000
509	2084.736750
510	2088.832500
511	2092.928250
512	2097.024000
513	2101.119750
514	2105.215500
~~515~~	~~2109.311250~~

AFS (TBD)

May be used for P2P links used in similar fashion (higher rates)

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Note: Consideration may be needed for TBD options to aid acquisition, such as adding short code on an orthogonal channel. Alternatively, users can adopt aiding features based on à priori knowledge of LunaNet provider node locations and PN Code number.

21 possible frequencies within 2025 – 2110 MHz

- $f_c = N \cdot R_c$ for $495 \le N \le 515$
- N = 495, 515 not recommended when considering signal bandwidth

Possible carrier frequency for AFS

- fc = 496 x 4.095750 Mcps = 2031.492000 MHz (TBD)

Augmented Forward Signal Structure (PFS5)

The AFS service is enabled using a spread spectrum signal, via Code Division Multiple Access (CDMA) in alignment with PFS5 Table 14. This allows different LunaNet sources to provide the AFS service simultaneously at a single and common S-Band frequency, as each source is assigned a different PN sequence pattern.

The AFS service is enabled by the use of the signal structure as defined above. In order to support simultaneous use of the AFS channel allocation, special considerations are required to maximize the ability for users to acquire and track the signals.

The signal power provided by LunaNet AFS sources will be dynamically adjusted to represent a minimum power of TBD and a maximum power of TBD at the lunar surface. The target location is specified as the nearest lunar surface location to the LunaNet source providing the signal, i.e., nadir point.

Additionally, to reduce the chances of multiple-access-interference (MAI) among LunaNet sources, information rates supported via AFS are limited to 868 bps (TBC). This is assuming LDPC 7/8 coding is implemented.

AFS Messages

Table C-3 - LunaNet Message Identification and Informatics for AFS Service

Message	ID	Update Rate	Latency	Cadence
LunaNet Network Access Information	MSG-G1			
Health and Safety	MSG-G3			
Acknowledge	MSG-G4			
Maneuver	MSG-G5			
SOrbit State	MSG-G7			
SOrbit Ephem	MSG-G8			
MOrbit State	MSG-G9			
MOrbit Ephem	MSG-G10			
SAttitude State	MSG-G11			
SAttitude Ephem	MSG-G12			
Conjunction	MSG-G13			
Time and Frequency Synchronization (fine)	MSG-G14			
Time Synchronization (coarse)	MSG-G15			

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Map	MSG-G16			
Ancillary Info	MSG-G17			
Search and Rescue	MSG-G18			
Detection Alert	MSG-G19			
Science	MSG-G20			

PRS 5/6 Signal Definition

The PRS5/PRS6 signal design enables simultaneous communication and navigation capabilities. These links can provide rates of up to 400 ksps (TBC). In terms of navigation, the signals support Doppler (1-way or 2-way), range, pseudorange and accurate time-transfer.

Refer to Table C-3 for specific signal characteristics.

Table C-4 - LunaNet PFS5/6 Signal Characteristics

Parameter	Value
Signal Type	CCSDS 415.1-B-1 (modified), suppressed carrier, CDMA, SS-BPSK
PN Chip Rate	
PN Code	Gold Codes, PN14 with length 16383
PN Periodicity	
Range Ambiguity	
Range Measurement Accuracy	
Bandwidth	
Symbol Rate	

Multiple Access Return Signal Structure (PRS5)

The Multiple-Access-Return service is enabled using a spread spectrum signal, via Code Division Multiple Access (CDMA). This allows different users to approach the LunaNet network simultaneously at a single and common S-Band frequency, as each source is assigned a different PN sequence pattern.

The Multiple-Access-Return service is enabled by the use of the signal structure as defined above. In order to support simultaneous use of the Multiple-Access-Return channel allocation, special considerations are required to maximize the ability for LunaNet to detect, acquire and track the signals.

Transmission of signals by users will be limited to the purposes of requesting services or conveying situational-awareness messages and search and rescue alerts.

The signals are to be transmitted for discrete, short periods of time [TBD – add timing scheme].

The signal power provided by users to the MAR channel will be transmitted with a minimum power of TBD and a maximum power of TBD.

Additionally, information rates provided via Multiple-Access-Return are limited to TBD bps.

MAR User Messages

Table C-5 - LunaNet Message Identification and Infomatics for User Multiple-Access-Return

Message	ID	Max Update Rate	Latency	Max Cadence
Request	MSG-G2			
Health and Safety	MSG-G3			
Maneuver	MSG-G5			
Observations	MSG-G6			
SOrbit State	MSG-G7			
SOrbit Ephem	MSG-G8			
SAttitude State	MSG-G11			
SAttitude Ephem	MSG-G12			
Conjunction	MSG-G13			
Map	MSG-G16			
Search and Rescue	MSG-G18			
Detection Alert	MSG-G19			
Science	MSG-G20			

Navigation Reference and Measurement Services VS Communication links

Tables C-6 and C-7 provide a relationship of navigation reference and measurement services as described in section 3.2. Link types beyond those identified for LunaNet interoperability are included for completeness.

Table C-6 - Navigation Reference and Measurement Services versus Forward Communication Links

PNT Service ID	Services	Band-Direction	S-Forward							Ka-Forward	Ka-Forward	Op-Forward
		Modulation	BPSK CCSDS 401.0-B-30	PCM/PM/Bi-phase-L (On residual carrier) CCSDS 401.0-B-30		PCM/PSK/PM (On subcarrier) CCSDS 401.0-B-30		SS-BPSK CCSDS 415.1-B-1 Alternative (TBD)	SS-UQPSK (10:1) CCSDS 415.1-B-1	OQPSK CCSDS 401.0-B-30	GMSK CCSDS 413.1-G-1 (TBD)	PPM
		Ranging	No Ranging	No Ranging	PN CCSDS 414.1-B-2	No Ranging	PN CCSDS 414.1-B-2	CDMA PN (TBD)	CDMA PN	Potential for telemetry ranging	PN CCSDS 414.1-B-2 (TBD)	Optimetrics
		Symbol Rates Supported	< 6 Msps	<= 1.024 Msps	<= 2 ksps??	<= 48 ksps	<= 2 ksps??	<= 400 ksps*	<= 300 ksps	>= 1 Msps	> 2 Msps	?
		ICSIS Compliant	Yes	Yes	Yes	Yes	Yes	No (TBD)	Yes (CSP-VV)	Yes	No (TBD)	?
		IOAG Compliant	Yes	Yes	Yes	Yes	Yes	Yes (TBD)	Yes	Yes	Yes (TBD)	Yes
		Interop Signal ID	Not Added	PFS1 / PFS3		Not Added	Not Added	PFS5 / PFS6	PFS2 / PFS4	PFKa1 / PFKa2 (not unique)	PFKa1 / PFKa2 (not unique)	Not Added
1wDRef		1-Way FWD Doppler Reference	X	X	X	X	X	X	X	X	X	X
1wRTRef		FWD Pseudo-Range and Timing Reference			Potential		Potential	X	Potential	Potential	Potential	TBD
1wDMeas		1-Way RTN Doppler Measurement										
1wRTMeas		RTN Pseudo-Range Measurement										
2wDMeas		2-Way Doppler Measurement	X	X	X	X	X	X	X	Potential Need Turn-Around defined	Potential Need Turn-Around defined	X
2wRMeas		2-Way Range Measurement			X		X	X	X	Potential Need Turn-Around defined	Potential Need Turn-Around defined	X
2wD-XPND		2-Way Coherent Doppler Transponder	X	X	X	X	X	X	X	Potential Need Turn-Around defined	Potential Need Turn-Around defined	TBD
2wNRR-XPND		Non-Regenerative Range Transponder			X		X					TBD
2wRR-XPND		Regenerative Range Transponder			X		X	X	X		X	TBD
TRef		FWD Time Transfer			Potential		Potential	X	Potential	Potential	Potential	TBD
AFS		Augmented Forward Service (AFS) (Simulataneously by More Than 1 Relay)						X *Symbol Rates ~1 ksps				
MAR		Multiple-Access Return (MAR)										

Table C-7 - Navigation Reference and Measurement Services versus Return Communication Links

PNT Service ID	Services											
		Band-Direction	S-Return							Ka-Return	Ka-Return	Op-Return
		Modulation	BPSK CCSDS 401.0-B-30	PCM/PM/Bi-phase-L (On residual carrier) CCSDS 401.0-B-30		PCM/PSK/PM (On subcarrier) CCSDS 401.0-B-30		SS-BPSK CCSDS 415.1-B-1 Alternative (TBD)	SQPN CCSDS 415.1-B-1	OQPSK CCSDS 401.0-B-30	GMSK CCSDS 413.1-G-1 (TBD)	PPM
		Ranging	No Ranging	No Ranging	PN CCSDS 414.1-B-2	No Ranging	PN CCSDS 414.1-B-2	CDMA PN (TBD)	CDMA PN	Potential for telemetry ranging	PN CCSDS 414.1-B-2 (TBD)	Optimetrics
		Symbol Rates Supported	< 6 Msps	<= 1.024 Msps	<= 300 ksps??	<= 48 ksps	<= 48 ksps??	<= 400 ksps*	<= 600 ksps	>= 1 Msps	> 2 Msps	?
		ICSIS Compliant	Yes	Yes	Yes	Yes	Yes	No (TBD)	Yes (CSP-VV)	Yes	No (TBD)	?
		IOAG Compliant	Yes	Yes	Yes	Yes	Yes	Yes (TBD)	Yes	Yes	Yes (TBD)	Yes
		Interop Signal ID	Not Added	PRS1 / PRS3		Not Added	Not Added	PRS5 / PRS6	PRS2 / PRS4	PRKa1 / PRKa2 (not unique)	PRKa1 / PRKa2 (not unique)	Not Added
1wDRef	1-Way FWD Doppler Reference											
1wRTRef	FWD Pseudo-Range and Timing Reference											
1wDMeas	1-Way RTN Doppler Measurement		X	X	X	X	X	X	X	X	X	X
1wRTMeas	RTN Pseudo-Range Measurement				Potential		Potential	X	Potential	Potential	Potential	TBD
2wDMeas	2-Way Doppler Measurement		X	X	X	X	X	X	X	X	X	X
2wRMeas	2-Way Range Measurement				X		X	X	X	Potential	X	X
2wD-XPND	2-Way Coherent Doppler Transponder		X	X	X	X	X	X	X	X	X	X
2wNRR-XPND	Non-Regenerative Range Transponder				X		X					
2wRR-XPND	Regenerative Range Transponder				X		X	X	X		Potential Need Turn-Around defined	
TRef	FWD Time Transfer											
AFS	Augmented Forward Service (AFS)											
MAR	Multiple-Access Return (MAR)							X *Symbol Rates ~TBD ksps				

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